

1 **“AUTOMATIC COLOR ADJUSTMENT FOR DIGITAL IMAGES”**

2 **CROSS REFERENCE TO RELATED APPLICATION**

3 This application is a continuation in part of pending US Patent
4 application Serial No. 09/548,755 entitled – VIRTUAL TRUE COLOR LIGHT
5 AMPLIFICATION, filed – April 13, 2000 and which claims priority of US
6 Provisional Patent application 60/129,041, filed April 13, 1999. The entire
7 disclosures of these applications are incorporated by reference herein in their
8 entirety.

9 **FIELD OF THE INVENTION**

10 The present invention related to methods for enhancing digital color
11 images. More particularly, the method automatically selects the extent to which the
12 strength of light is amplified in correcting color digital images without exceeding the
13 inherent dynamic range for the image. Further, an automated method corrects
14 faded or washed out images.

15
16 **BACKGROUND OF THE INVENTION**

17 **LIGHT AMPLIFICATION OF IMAGES**

18 If one were to photograph the stain glass windows of a Cathedral, the
19 resulting image would be typically too dark for modern tastes. The beauty of the
20 actual stained glass is lost. Further, a photographer can increase depth of field of
21 an image by reducing the device's aperture, but light collection is sacrificed and can
22 also result in a dark image. Further, as a still image device is capable of only

1 HSV color space, Kuo then isolates and removes the color information (Hue) from
2 the remaining image components (saturation and intensity). Kuo suggests that the
3 components of saturation and intensity can be enhanced without introducing
4 distortion into the color or Hue component. Kuo's color image is represented by a
5 plurality of pixels in HSV color space. Once transformed, Kuo inverse transforms
6 HSV back to RGB color space, all the while claiming this to be efficient. In the
7 preferred embodiment, Kuo adjusts intensity (V) and saturation (S). In summary,
8 Kuo first transforms RGB to HSV color space, applies two sequential transformation
9 functions to V and S respectively, and finally inverse transforms the altered HSV
10 back to RGB for display.

11 Respectfully, Applicant asserts that manipulation of the saturation
12 does affect the color and thus the Kuo technique does not result in true color
13 enhancement. Color photos have three degrees of freedom, being R,G and B,
14 where as black and white photos only have one. Any transformation of the three
15 values results in three more values, each of which contains a color component and
16 not merely a single color value (i.e. hue) and two other independent structural
17 components (i.e. saturation and intensity). Hue may be a more extreme sense of
18 color than saturation, but saturation is still a color component. Adjusting a dot's
19 saturation results in a change in the proportions of RGB in the dot and hence its
20 color. If the saturation is changed, say as part of brightening the image, the result is
21 not the same as if the recording device or camera had obtained the image directly
22 from the real world subject under brighter conditions, or more exposure.

1 Further, note that Kuo emphasizes and attempts to minimize the
2 computational overhead or expense. Unfortunately, Kuo introduces two RGB-HSV
3 and HSV-RGB transformations in addition to whatever adjustments (preferably two)
4 Kuo makes to the HSV pixel. A transformation from RGB to HSV color space, and
5 back again, involves the use of computation-intensive mathematical functions.

6 Further, the foregoing methodologies rely on significant user input and
7 skill.

8

9 AUTOMATIC CORRECTION

10 It is known to automatically corrects tone values of digitally stored
11 images as disclosed in US patent 5,544,258 to Levien. A histogram of the image is
12 processed by adding a constant, applying a non-linear function to each value, and
13 digital filtering. Application of a square root function assures that small histogram
14 values have more contribution to the final curve, and that large histogram values
15 have less contribution to the final tone curve, relatively. The processed histogram is
16 integrated and then normalized for a tone correction function. This tone correction
17 function can be applied to the average histogram of the respective individual color
18 planes. It is applicant's view that this correction does not maintain the true colors
19 through the correction nor deal with limitations of dynamic range.

20 Accordingly, there is demonstrated a need for an automatic and
21 computationally efficient process which is capable of maintaining true color for each

1 dot during enhancement of an image. Automation avoids the barrier of a steep
2 learning curve to effectively adjust images for more a pleasing effect. The present
3 invention addresses these problems by providing a technique which is both
4 automated and which, no matter how much image-brightening is needed or what
5 the nature of that brightening is, the color of all dots in the image are preserved.

6

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SUMMARY OF THE INVENTION

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The present invention applies the virtual true color correction
9 techniques of the co-pending application in an automated methodology for further
10 simplifying color light amplification of digital photographs without color distortion. In
11 one embodiment, the present invention automatically applies an average strength
12 value for a digital image and determines a corresponding correction function for
13 maximal amplification without color distortion. In another embodiment, the method
14 is further improved through automatic compensation for distorted or faded digital
15 photographs.

16 In one broad aspect of the invention, automatic adjustment of the color
17 of a digital image comprises: establishing an original histogram of dot maximums for
18 the plurality of color dots within the original image and an original average strength
19 thereof; amplifying each dot maximum with a scaling factor selected from a
20 continuous scaling function to obtain a scaled dot maximum which is less than or
21 equal to the maximum of the dynamic range; establishing a corrected histogram of
22 scaled dot maximums and a corrected average strength thereof; interpolating a

1 target scaling factor from a target average strength, the corrected average strength
2 and the original average strength for each dot maximum; and creating the adjusted
3 image without color distortion by applying the target scaling factors to each color
4 dot's R, G and B strength values so that a histogram of the adjusted image has the
5 target average strength and that the ratios of the strength values between R, G and
6 B for the color dot remain the same after scaling as they were before scaling.

7 In some cases it is preferable to automatically correct the image for
8 removing excessive gray before automatic adjustment of the color further
9 comprising: establishing a supplied histogram of R, G, or B strength values for each
10 color dot within the supplied image; determining a offset strength value between the
11 minimum of the dynamic range of the system and a minimum threshold strength
12 value of the supplied histogram; and subtracting the offset strength value from each
13 R, G, and B value for forming the original image for automatic correction thereof.

14

BRIEF DESCRIPTION OF THE DRAWINGS

VIRTUAL TRUE COLOR LIGHT AMPLIFICATION

In the Figures, several digital images are presented. As this application is directed to the enhancement of color digital images without suffering a distortion in color, the results cannot be properly reproduced herein in the gray scale printing medium.

Figure 1 is a graph representing a linear function as the basis for correcting each R,G or B dot maximum as input to an adjusted output dot maximum, both of which are constrained to the system's dynamic range. This particular function would be a unity function, and would not perform any correction unless the input is normalized to the dynamic range by pre-scaling the maximum of the dot maximums to 1.0;

Figure 2 is a brief coding example in Visual Basic for reading a digital screen image, extracting color dots, finding a dot maximum, applying a correction factor for the dot maximum, applying the correction to the entire RGB values for a dot and writing the corrected color dot back to the screen;

Figure 3 is a graph illustrating a scaling function designed to modify an image which was intentionally underexposed, such as by using a small aperture so as to obtain improved depth of field;

Figure 4 is a graph illustrating a scaling function which enhances the contrast within a specific area of the dot maximums, falling between 0.3 – 0.5 of the

1 image's range, by scaling 20% of the range to nearly 100% or substantially the
2 entire dynamic range, and wherein the darker and lighter areas contrasts are
3 diminished;

4 Figure 5 is a graph according to Fig. 4 which enhances the dot
5 maximums in the dark area falling between 0.1 – 0.2 of the image's range;

6 Figure 6 is a graph according to Fig. 4 which enhances the dot
7 maximums in the bright area falling between 0.9 – 1.0 of the image's range;

8 Figure 7a is a brief coding example in Visual Basic for using a GUI
9 interface to select an x1,y1 and x2,y2 window area, reading the digital screen image
10 in the window, extracting color dots, finding a dot maximum, applying a correction
11 factor for the dot maximum, and building a histogram of dot maximum occurrences;

12 Figure 7b is a brief coding example in Visual Basic for generating the
13 histogram according to the third embodiment.

14 Figure 8 is a graph illustrating variable scaling functions superimposed
15 over a unity diagonal, the variable functions produce an aesthetically pleasing
16 enhancement through the brightening of the image. The scaling functions are
17 smooth curves, one a factor of the other, such as a third order curve, which de-
18 emphasizes the darker areas and brightens the lighter areas;

19 Figures 9a – 9f are photographs of an Abbey which are respectively,
20 the original, brightened under the prior art, brightened and contrast adjusted under
21 the prior art, brightened and saturation adjusted under the prior art, enhanced

1 according to the first embodiment of the present invention to the full dynamic range
2 and enhanced according to the second embodiment of the present invention;

3 Figures 10a – 10f are photographs of Stone Henge which are
4 respectively, the original, brightened under the prior art, brightened and contrast
5 adjusted under the prior art, brightened and saturation adjusted under the prior art,
6 enhanced according to the first embodiment of the present invention to the full
7 dynamic range and enhanced according to the second embodiment of the present
8 invention;

9 Figures 11a and 11b are respectively an original photo of a satellite
10 and an enhanced photo according to the third embodiment of the present invention;

11 Figures 12a and 12b are respectively an original photo of a blimp and
12 an enhanced photo according to the third embodiment of the present invention;

13 Figures 13a and 13b are respectively an original photo of a car license
14 plate and an enhanced photo according to the third embodiment of the present
15 invention;

16 Figures 14a, 14b and 14c are respectively an original photo of skiers
17 and ski tracks in the snow and two enhanced photos according to the third
18 embodiment of the present invention, each using a different portion of the photo to
19 build the enhancement; and

20 Figure 15a is a flow chart of one embodiment of the invention
21 illustrating determination of scaling factors;

1 Figure 15b is a flow chart of another embodiment of the invention
2 illustrating determination of scaling factors and storing them in a lookup table;

3 Figure 15b is a flow chart of another embodiment of the invention
4 illustrating determination of scaling factors and application of a function to adjust the
5 color dots;

6 Figure 16 is a flow chart of another embodiment of the invention
7 illustrating a normalization process for the dots to at least a portion of the dynamic
8 range such as that set forth in the third embodiment; and

9 Figure 17 is a flow chart of another embodiment of the invention
10 illustrating a selection of a portion of the image for adjustment and two
11 implementations of the invention to adjust the image;

12 Figures 18a and 18b are respectively a first histogram of a supplied
13 image which is faded or has an excessive gray present, and a second histogram of
14 an image which has been offset to remove gray according to an automatic
15 correction embodiment of the present invention;

16 Figure 19 is a graph according to Fig. 8 further illustrating a variety of
17 scaling functions superimposed over an identity function or unity diagonal, one non-
18 linear curve representing a nominal correction which can be adjusted to an
19 interpolated target function which better produces an aesthetically pleasing
20 enhancement through the brightening of the image; and

1 Figure 20 illustrates three comparative histograms including a second
2 histogram H_o of an offset image forming an original image for brightening according
3 to Fig. 18b, a third histogram H_c of the corrected image at 100% application of the
4 scaling function C according to Fig. 19, and a fourth histogram H_T of a final
5 corrected image at the interpolated and fractional correction of the scaling function
6 T to achieve a target average strength.

7

8

1 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

2 VIRTUAL TRUE COLOR LIGHT AMPLIFICATION

3 The present invention disclosed herein implements a new method for
4 automating techniques for amplifying the brightness of color digital images, the
5 basics for brightening images being are set forth in co-pending application Serial
6 No. 09/548,755 to the applicant, the entirety of which is incorporated herein by
7 reference. A substantial portion of the co-pending application is reproduced herein.

8 First, an image is captured using some form of digital image recorder.
9 Digital image recorders fall into two categories: physical and virtual. Physical digital
10 image recorders are devices that record a digital image by the measurement of light
11 energy; such as a digital cameras. Like a traditional film camera, digital cameras
12 have a 'lens complex' that provides light gathering and the image is recorded by an
13 array of digital sensors so that the value of each dot represent actual
14 measurements of the light. A digital image can also be obtained as a digital scan of
15 a traditional photograph. In a photograph, light gathering was provided by a
16 traditional camera and the image was recorded on film. Accordingly, a physical
17 digital image recorder can be a combination of camera that produced the film/print
18 image and a scanner that digitized it. Other examples include digital movies,
19 digitized movies, digital x-rays, and the like.

20 Virtual digital image recorders are computer renderings that imitate
21 reality. The programs create a 'virtual image' (as in virtual reality) by a logical
22 imitation of the photographic process completely internal to the computer itself.

1 These digital images are what a photograph would have looked like had a
2 'computer model' actually existed. An example is those movies with stunning
3 dinosaur simulations.

4 A lens complex is the apparatus that gathers light in various forms of
5 photography. There is at least one lens and usually a system of such lenses. The
6 lens complex also includes an aperture stop and a shutter which are both controls
7 on the light gathering.

8 The light gathering power of a lens is often measured in terms of the
9 surface area of the objective lens itself. A lens with twice the area of another can
10 gather twice the light. In practice, a lens complex has two controls on the amount of
11 light actually gathered. The first control is the adjustable aperture which varies the
12 amount of light that is collected per unit time. Twice the area means twice the light
13 per unit time. The second control is called the shutter and it varies the amount of
14 time that light enters the body of the camera. Holding the shutter open twice as
15 long means that twice the light energy enters the camera.

16 A true color digital image comprises a grid of dots wherein each dot
17 has three independent measured values representing the strengths of the red,
18 green and blue (RGB) components of the light. This is known as RGB color space.
19 There are various computer file formats used for these images, using various
20 'compression schemes' to save computer disk storage space. Regardless of
21 compression scheme, all such digital file formats store a grid of dots with RGB
22 values.

1 Currently, the common standard maximum value stored by such files
2 or a system, for each of the R,G, or B value, is 255. Accordingly, each of the RGB
3 components can range in strength from 0 to 255. Some file formats now store
4 values in the range of 0 to 1023, and higher formats are likely.

5

6 Dynamic range

7 Every device, including our digital image recorder, has a 'dynamic
8 range' which is a measure of its ability to record relative energy fluctuations. As
9 stated above, this dynamic range is usually set by the storage means, file or system
10 and is typically 0 – 255. In photography, the trick to success is to use all the
11 dynamic range without exceeding it. In a photo, the trick is to capture both the
12 details in bright areas and details in dark areas without a loss of details anywhere.

13 In film photography, when a significant area of the negative has turned
14 completely opaque it means that the light was so intense in that area that no film
15 crystals were left unchanged. The variations within the washed out area of the
16 photograph are lost and can be said to 'have exceeded the dynamic range of the
17 system'.

18 In digital photography, the strength of the light energy is measured by
19 the photo-electric sensors. These values are stored as a true color format computer
20 file. The dynamic range of the system is exceeded when areas of the grid have
21 been set to the maximum (say 255). Accordingly, variations within the bright areas,

1 hypothetically 256 - 300 can only be recorded as 255 and thus details within such
2 areas are lost.

3 With a limited dynamic range, as is the case with digital images, the
4 amount of light which is captured can significantly affect the image. Consider if one
5 image is obtained containing one particular dot of light which is measured within the
6 dynamic range of the recording device. For example, the light may come from a
7 brown surface. The light dot is measured in terms of three color strengths, the red
8 (R), green (G) and blue (B). If a second image is obtained having had double the
9 exposure time, then twice as much light will go into the recording device for each
10 and every dot, including the dot we are considering. If the range of light remains
11 within the dynamic range of the system, then all the three values of R, G, and B will
12 be doubled – yet the color of the original brown dot remains as brown. Doubling of
13 the incoming light means its strength measurement will be doubled – R is doubled,
14 G is doubled and B is doubled.

15 In the case of digital information, for example, upon a doubling of the
16 light (through a larger aperture or longer exposure), relative RGB values are also
17 doubled. RGB values of 50,30,20 are doubled to 100, 60,40, because $100 = 50 \times 2$,
18 $60 = 30 \times 2$, and $40 = 20 \times 2$.

19 When twice as much energy hits each sensor, then each sensor has
20 twice the stimulation. Twice as much red energy hits the red sensor and the other
21 energy doesn't matter to it. Twice as much green energy hits the green sensor.
22 And twice as much blue energy hits the blue sensor.

As the light gathering power increases, the three measurements of the primary colors of the same dot increase proportionally as shown in the following Table 1 – hence the color remains the same, only brighter.

Table 1. - Effect of Increasing Light Gathering Power on Measurements of RGB

Light Gathering Power	Description	Red	Green	Blue	Green/Red	Blue/Red
1	"Reference, one unit"	50	30	20	0.600	0.400
1.1	Up 10%	55	33	22	0.600	0.400
1.2	Up 20%	60	36	24	0.600	0.400
1.3	Up 30%	65	39	26	0.600	0.400
1.4	Up 40%	70	42	28	0.600	0.400
1.5	Up 50%	75	45	30	0.600	0.400
2	Double	100	60	40	0.600	0.400
2.5	Two and a half times	125	75	50	0.600	0.400
3	Triple	150	90	60	0.600	0.400
4	Four times	200	120	80	0.600	0.400
5	Five times	250	150	100	0.600	0.400

In Table 1, note that the ratio of Green/Red and the ratio of Blue/Red remain constant, regardless of the light gathering power.

The reference level for light gathering power is artificial, a matter of convenience. What is the 'correct' measurement of the color of the dot of Table 1? An image collected from an overcast outdoors environment may measure the color dot at 50,30,20 and the color dot measured in a bright indoor setting could be 200,120,80 utilizing four times the light gathering power.

1 While it is possible to calibrate light gathering power in terms of the
2 energy that is collected, it is rarely done in practice. The light gathering power of
3 our own eyes naturally varies. City lights that seem so very bright at night appear
4 dull in daylight because the eye's iris automatically opens at night and then closes
5 during the day, as is required to deal with the natural extreme variations in light
6 level. Applicant is not aware of a recording device that has a wide enough dynamic
7 range to handle the range from natural daylight to artificial city night lighting with the
8 same light gathering settings. What makes a good image is, in part, that the light
9 gathering ability is varied with the light - so that the recording is not pushed outside
10 of the dynamic range. Both measurements of 50,30,20 and 200,120,80 for the
11 same color or dot are valid.

12 For any set of three numbers, such as the intensity values for each of
13 Red, Green, and Blue, there are a total of six possible ratios and they are G/R, B/R,
14 G/B, R/G, R/B, and B/G. Only two of the ratios are unique, the other four ratios are
15 redundant as they are variations of the first two.

16 For example, based upon G/R and B/R, the others are:

17 green/blue = (green/red) / (blue/red)
18 red/green = 1 / (green/red)
19 red/blue = 1 / (blue/red)
20 blue/green = (blue/red) / (green/red)

21 In principle, any two of the six can be chosen. For the purposes of
22 this description, the ratios of green/red and blue/red are chosen.

1 An efficient choice for the value of the strength of the RGB triplet
2 would be to simply take the maximum value from amongst the three RGB values. In
3 the case of 50,30,20 for RGB respectively, red happens to be the maximum value
4 and the calculation of strength and the two ratios becomes:

$$\begin{aligned}5 \quad \text{Strength} &= \text{red} = 50 \\6 \quad \text{Ratio1} &= \text{green/red} = 30/50 = 0.600 \\7 \quad \text{Ratio2} &= \text{blue/red} = 20/50 = 0.400\end{aligned}$$

8 In reverse, one can back-calculate and recover the red, green and
9 blue values as follows:

$$\begin{aligned}10 \quad \text{red} &= \text{Strength} = 50 \\11 \quad \text{green} &= \text{Strength} * \text{Ratio1} = \text{red} * \text{green} / \text{red} = 50 * 0.600 = 30 \\12 \quad \text{blue} &= \text{Strength} * \text{Ratio2} = \text{red} * \text{blue} / \text{red} = 50 * 0.400 = 20\end{aligned}$$

13 This artificial representation of the RGB triplet is useful because, for
14 any dot, the two ratios are independent of the light gathering power. The amount of
15 light gathered only affects the strength component.

16 Too much light gathering will cause the measurement of the color to
17 become distorted because at least one of the three primary colors RGB will exceed
18 the dynamic range and thus will not be accurately represented. Consider the
19 previous example dot of 50, 30, 20 at some arbitrary reference level of light
20 gathering power. If the image is re-recorded, but at a much higher light gathering
21 power, then at least one color will be pushed beyond the dynamic range.

1 **Table 2. - Increasing Light Gathering Power beyond the Dynamic Range of System**

2 Light
3 Gathering

4	Power	Description	Red	Green	Blue	Green/Red	Blue/Red
5	1	Reference	50	30	20	0.600	0.400
6	3	Triple	150	90	60	0.600	0.400
7	5	Five times	250	150	100	0.600	0.400
8	5.1	5.1 times	255	153	102	0.600	0.400
9	5.2	5.2 times	255	156	104	0.612	0.408
10	6	Six times	255	180	120	0.706	0.471
11	7	Seven times	255	210	140	0.824	0.549
12	8	Eight times	255	240	160	0.941	0.627
13	9	Nine times	255	255	180	1.000	0.706
14	10	Ten times	255	255	200	1.000	0.784
15	11	Eleven times	255	255	220	1.000	0.863
16	12	Twelve times	255	255	240	1.000	0.941
17	13	Thirteen times	255	255	255	1.000	1.000
18	1	"Reference, one unit"	50	30	20	0.600	0.400

19 Notice that neither the ratio of green/red nor blue/red are constant
20 (because they have saturated) past 5.1 times the light gathering power. Because
21 there is a maximum amount of energy that can be measured by the recording
22 device (either digital sensors or film) there is a practical limit to the useful light
23 gathering power for any subject. In Table 2, when light gathering power exceeds
24 five times the reference power, the dynamic range is almost fully used. The
25 strength of the dot is 250 and the maximum that can be stored is 255. That
26 maximum is reached, exactly, at 5.1 times the light gathering power. At 5.1 the
27 strength of the dot is 255 yet the two ratios are still 0.600 and 0.400 respectively. At
28 5.2 times the light gathering power, even more light enters the recording device.

1 The red sensor would have stored the number 260 but it cannot because the
2 dynamic range is surpassed and the value is clipped to 255 instead. The correct
3 numbers are stored for both the green and blue sensors, however, the incorrect
4 total color is recorded and this is revealed by noticing that the two ratios now vary
5 from the proper ratios of 0.600 and 0.400. At 6 times the light gathering power,
6 even more light enters and the distortions are correspondingly greater. The ratios
7 are now significantly different and incorrect at 0.706 and 0.471 and these
8 correspond to a significantly different color. At 8.5 times the light gathering power,
9 the blue sensor also measures clipped values. The light is recorded as having the
10 same strength in both the red and blue primary colors. The blue to red ratio is now
11 1.000 and the previous distorted color (reddish brown) now further distorts to an
12 orange. Finally, at 12.25 times the light gathering power, all three sensors clip and
13 the color is recorded as three full strength primary colors, meaning white.

14

1 It is important to avoid collecting light beyond the ability of the
2 recording system (it's dynamic range) because it causes distortion in the color.

3 Any one of the RGB triplet can be chosen as the reference color. If
4 green was the strongest color, and assuming the color was 30,50,20 (having the
5 same reference light gathering power as the previous red example), then having
6 reference to Table 3, the same behavior is exhibited.

7 **Table 3. - Effect of Increasing Light Gathering Power with Green as strongest color**

8	Light						
9	Gathering						
10	Power	Description	Red	Green	Blue	Green/Red	Blue/Red
11	1	Reference	30	50	20	1.667	0.667
12	3	Triple	90	150	60	1.667	0.667
13	5	Five times	150	250	100	1.667	0.667
14	5.1	5.1 times	153	255	102	1.667	0.667
15	5.2	5.2 times	156	255	104	1.635	0.667
16	6	Six times	180	255	120	1.417	0.667
17	7	Seven times	210	255	140	1.214	0.667
18	8	Eight times	240	255	160	1.063	0.667
19	9	Nine times	255	255	180	1.000	0.706
20	10	Ten times	255	255	200	1.000	0.784
21	11	Eleven times	255	255	220	1.000	0.863
22	12	Twelve times	255	255	240	1.000	0.941
23	13	Thirteen times	255	255	255	1.000	1.000

24 As shown, the same situation occurs wherein the green/red and
25 blue/red ratios become distorted in a very similar manner. In this case, the ratios
26 red/green and blue/green produce the same numbers (0.600 and 0.400) as in the
27 previous 50,30,20 illustration for the case of red.

1 Accordingly, regardless of which of the RGB triplet is the maximum,
2 there is a symmetry and strength is defined as the maximum strength value of (Red,
3 Green, and Blue) and color ratios result (red/Strength, green/Strength,
4 blue/Strength). One of the three ratios will be exactly equal to 1 because strength is
5 always equal to one of the numerators. In the case of Red from Table 1, RGB =
6 50,30,20 so that strength = max of (50,30,20) which is 50 and the color ratios are
7 (50/50, 30/50, 20/50) = (1, 0.600, 0.400).

8 Thus, for Red, Green and Blue respectively:

9	<u>Color</u>	<u>Strength</u>	<u>R/S</u>	<u>G/S</u>	<u>B/S</u>
10	50,30,20	Red	1	0.6	0.4
11	30,50,20	Green	0.6	1	0.4
12	30,20,50	Blue	0.6	0.4	1

13 As considered before, when a camera gathers more light compared to
14 another setting for the same image, a given dot has the qualities that the ratios of
15 the measured primary colors remain the same - if we are within the dynamic range
16 of the recording system. Instead of thinking of the dot as an RGB triplet we can
17 think of the dot as a strength and ratios. Again, for our dot, 50,30,20 at its reference
18 strength of 50, the color ratios are 1, 0.600 and 0.400.

19

20

1 Enhancing the Image

2 As long as the color ratios are unaltered, the image can be adjusted
3 without adversely affecting the colors. For instance, should insufficient light have
4 been gathered by the recording device, we can virtually amplify the light power or
5 strength while maintaining the color.

6 To virtually amplify or scale the light by a correction factor of 2, the
7 strength is doubled without varying the color ratios: For example, doubling the
8 strength of our dot of (50,30,20) to 100 results in a color dot of $50 * 2 * (1,0.6,0.4) =$
9 $(100,60,40)$. Simply, the same result can be achieved by simply multiplying the
10 R,G, and B by 2.

11 This virtual true color light amplification is accomplished by multiplying
12 or scaling all three primary colors by the same number. No colors become
13 distorted, as long as the output values stay within the dynamic range. The dynamic
14 range is exceeded if a R, G, or B value is calculated that is greater than the range
15 used by the file format for the image (such as 255).

16 One can ensure that no value, resulting from the triple multiplication
17 scaling, can exceed the dynamic range, by deriving the correction from an algebraic
18 scaling expression or function.

19 Having reference to Fig. 1, the X-axis represents the strength of an
20 image dot (Maximum of red, green, and blue). The scales of 0 – 1 represent the
21 limits of the dynamic range (such as 0 – 255). For the linear diagonal shown, a

1 strength of 50 ($50/256 = 0.2$) for a dot is scaled by unity for an output value of 0.2.
2 Accordingly, the unity diagonal corresponds to a 'no operation' situation where the
3 output is identical to the input. However, once the scaling function deviates from
4 unity, the output values will be different from the input values, resulting in a change
5 to the image.

6 To scale the dynamic range from 0 to 1.0 is to simply divide a current
7 strength (maximum of the RGB triplet) value by the maximum number that can be
8 stored with this dynamic range. Suppose that number is 255. An arbitrary dot will
9 have a dot maximum strength having a number between 0 and 255. To scale the
10 dot maximum to 0 and 1.0 one divides the strength by 255.

11 Both the input and the output axis represent the values of the
12 maximum of the RGB triplet; the dot maximum. The input is the dot maximum
13 under consideration. The output corresponds to the adjusted dot maximum for the
14 RGB triplet that will be calculated as a result of the method.

15

16 Dot Maximum

17 One method to find the maximum of an input RGB triplet is to choose
18 one as maximum, testing each of the others, and resetting the maximum to that
19 other if higher.

20

1 The following 3 lines of pseudo code illustrated the selection of a dot
2 maximum:

```
3                   strength = red  
4                   strength is set to red value  
5                   IF strength < green THEN strength = green  
6                   if strength is less than green value then reset it to the green value  
7                   IF strength < blue THEN strength = blue  
8                   if strength is less than blue value then reset it to the blue value
```

9 Having reference to Fig. 1, any scaling or correction is constrained to
10 the 1 X 1 graph shown. The input axis is constrained to the domain from 0 to 1 and
11 the output axis is constrained to the range of 0 to 1. This means that the strength of
12 an adjusted or corrected dot will not exceed the dynamic range.

13 Any scaling function that can be plotted within the constrained graph
14 can be used for virtual true color light amplification. The properties of a particular
15 graph will affect the final aesthetics and application. A particular function is chosen
16 as appropriate for the application; whether it be to adjust the brightness of an entire
17 image, or a portion of the image, or other adjustment.

18 Two implementations of the scaling function correction include forming
19 a lookup table of corrections (a finite number dictated by the dynamic range); and
20 another less efficient means is to calculate each dot independently in turn. One can
21 understand that in an image, the value of the strength of a particular dot may be
22 repeated many times for many other dots. Thus, for efficient calculation, in the case
23 of a look-up table, a correction can be calculated only once but applied many times.

1 For the look-up table approach, once the parameters needed to
2 specify a particular scaling function are known - all the corrections (usually 256 of
3 them, this depends on the limit of the dynamic range) are then calculated by means
4 of a subroutine and the results stored in a look up table so that each is only
5 calculated once. The correction is then simply looked up in this way (a pseudo
6 coded example is:)

7 **corr = corra(strength)**

8 where corr is the particular correction for the current dot;
9 corra() is the lookup table or array that stores the corrections; and
10 strength is the dot maximum of the RGB for the current dot.

11 The other (less efficient) way is to have a function calculate the
12 correction for a particular dot, each one in turn. An example would be

13 **corr = correct(strength)**

14 where corr is the particular correction for the current dot;
15 correct () is the correction function which executed by
16 simply 'calling' its name in this way; and
17 strength is the dot maximum of the RGB for the current dot.

18 A given point along the graphed scaling function, which provides an
19 input and output value, is to be used to derive the correction multiplier or factor. A
20 correction factor is equal to output value / input value.

21 So as to maintain the respective color ratios, all three of the RGB
22 triplet values are multiplied by this same correction **corr** as determined for and
23 specified by the dot maximum.

1 Accordingly, $\text{red} = \text{red} * \text{corr}$; $\text{green} = \text{green} * \text{corr}$; $\text{blue} = \text{blue} * \text{corr}$
2 where red, green, blue end up holding the values for the current dot before and after
3 correction. The effect of coupling these four considerations is that of Virtual True
4 Color Light Amplification. The Dynamic Range is never exceeded and the color is
5 always preserved.

6

7 Practical Implementation

8 An image can be read in various ways. Applicant has avoided the
9 need to review the various graphical computer file formats by illustrating the method
10 on a displayed image. Applicant is aware that, currently, Visual Basic (a
11 programming language operable under the Windows operating system – all
12 trademarks of Microsoft Corporation) and most other modern programming
13 languages have simple commands that allow for image reads. In Visual Basic, one
14 command is `pbox.Picture = LoadPicture(file_in)` where pbox is a 'picture box object',
15 used for displaying pictures, Picture is a 'method' which assigns a picture to the
16 object, LoadPicture() is the function that reads Picture Files, and file_in is the name
17 of the file that is to be read. Once this command is issued by Visual Basic, the
18 image file is read in and displayed on the screen in the programming 'tool' called the
19 'picture box object'. There is a similar method to save a picture.

20 Having reference to Fig. 2, the simplified code illustrates a Visual
21 Basic implementation of the virtual true color light amplification method applied to
22 an image. This simplified technique requires, at a minimum, a 16 bit video card and

1 a 24 bit card is preferable. The code of Fig. 2 is directed to extracting color values
2 from the video card itself. This is not the most efficient technique and could be
3 improved significantly by storing the image in the main RAM memory. This would
4 eliminate accessing the video card at all and eliminate the extraction steps of
5 stripping R, G and B values from a combined color variable such as that returned by
6 Visual Basic function pbox.Point(icol,irow). Accessing memory could result in about
7 a 7 times efficiency gain.

8 Simply, the process permits a rectangular displayed image of dots to
9 be adjusted. For example, the image may be dark, only having a maximum
10 strength for any of the dot maximums being about 128, or half the dynamic range
11 for the system. In the simplest case, the image range is scaled to the dynamic
12 range as a linear function. Accordingly, by normalizing the maximum of 128 to 255,
13 the strength of all dot maximums will be doubled. Accordingly, the scaling function
14 is merely a constant of 2 and the look up result, for any dot maximum, is 2. For
15 each column of the image, the values of the color are extracted for blue, green and
16 red. The dot maximum is set as red and the green and blue are tested to reset the
17 strength to the maximum amongst the three. The correction is looked up in the
18 table, in this case being a constant of 2. Each of the values for RGB are scaled by
19 2, the maximum scaled value being $128 * 2$ or 256 – the maximum of the dynamic
20 range. The modified dot is written back to the display, all colors having been
21 preserved and without having exceeding the dynamic range.

22

Applications – Effect of the Scaling Function

The virtually infinite selection of scaling functions, as applied to the image, results in different effects to suit various differing objectives. Sometimes the quality of the image dictates which function is used (such as a function designed simply for brightening a dark image), or a more particular function which enhances only specified strengths within an image (such as extracting detail from a narrow portion with minimal concern regarding the effect on the other portions of the image).

Applications – Virtual Lens

Both the aperture and the shutter cause problems in and of themselves. If the subject of the photograph is moving, the shutter can only be open for a short period of time or the image will be blurred by the motion itself.

When the aperture is opened up, the depth of field (which means the range of distance that is in focus) decreases. Even when focusing correctly, a wide open aperture means that only a small range of distance will be in focus. This 'distortion' is due to the spherical shape of the lens itself. When the aperture is small, the depth of field is better because only the nearly flat center of the lens was used. The smallest aperture setting provides the largest depth of field.

In practice, photography (and light gathering in general) is a trade off of these two effects. A motionless scene can have a large depth of field, by

1 choosing a small aperture and a slow shutter speed. A racing car can only be
2 photographed at the cost of the depth of field, the shutter cannot be open for long
3 and so the aperture must be opened to gather more light.

4 Suppose that a 'normal' quality lens is used to photograph something
5 that is moving quickly but the photographer does not want to lose the depth of field.
6 Without the process of the present invention there is no way to do this. Accordingly,
7 by setting the controls to gather too little light, in terms of normal photographic
8 thinking, the uncorrected image will be too dark but the depth of field is preserved.
9 Suppose the photographer had collected a quarter (25%) of the amount of light that
10 would make full use of the dynamic range. The image will be nearly black, with the
11 highest value recorded being 63 whereas the dynamic range limit is 255. This
12 image can be corrected to bring out the detail in the dark areas.

13 Accordingly, in a first embodiment, and having reference to Fig. 3, the
14 graph is a straight line which terminates at the point $(x, 1.0)$ where x is the
15 maximum of the entire measured image. This maximum value can be found using a
16 modified histogram approach. In this example, x would be 0.25 but it could be any
17 value between 0 and 1. In the preferred embodiment of the invention, virtual light is
18 added in the same way that opening the aperture more would have except that it
19 will have a depth of field associated with a superior lens. This process can also be
20 used to make up for 'blunders' where inappropriate lens settings resulted in a too
21 dark photograph.

22

1 Virtual Iris

2 In a second embodiment, and having reference to Fig. 8, a graph can
3 be chosen so that the darkest parts of the image will remain dark, the duller parts
4 will brighten but also so that the bright parts of the image remain nearly unaffected.
5 Fig. 8, and similarly shaped smooth non-linear graphs, have the effect of imitating
6 the iris when used with the virtual true color light amplification of the present
7 invention. The output image happens to more closely resemble one's visual
8 memory of the experience. Applicant refers to this enhancement as “virtual iris”.

9 The gentle nature of this non-linear graph ensures that a quality input
10 image will result in an attractive processed image. The important aspects to
11 maintain this aesthetic result is that the graph remains smooth, the slope of the
12 graph is never zero and is also smoothly changing, and that there is a net
13 brightening effect in total.

14 In Fig. 8, the scaling function approaches the asymptote of the
15 minimum and maximum of the system's dynamic range. The more the function
16 approaches a tangent to the minimum and maximum of the dynamic range, the
17 more severe the correction.

18

19 Virtual Detail Enhancement

20 Simply, any one frame of a photo is the result of only one aperture and
21 shutter setting. In investigative work, this has the annoying limitation that details in

1 certain areas of the photograph will be subtle. In a third embodiment, a process is
2 provided for bringing out detail in that certain subtle area.

3 Having reference to Fig. 4, an area of interest is chosen and a
4 histogram approach is applied to find that the minimum strength dot within the area
5 is 0.30 and the maximum strength dot is 0.50. This area utilizes only 20% of the
6 dynamic range, which means that the contrasts will be subtle – or virtually
7 indistinguishable to the eye.

8 Applying a three part linear scaling function as shown in Fig. 4 turns
9 these small contrasts into large ones as the output from that specified area now
10 varies over 80% of the dynamic range.

11 The small sloped lines below 0.30 and above 0.50 on the input have
12 the effect of washing out the detail in darker and brighter parts of the image. But
13 the resulting color, at each dot, will never be corrupted and the brighter parts of the
14 image provide a good reference.

15 Any area of the photograph can be chosen. Having reference to
16 Fig. 5, details in a very dark area are revealed, such as writing obscured in shadow.
17 Fig. 6 illustrates how to bring out the details in a bright area, such as tracks in the
18 snow. Any number of areas can have their detail enhanced by simply choosing the
19 area of interest and applying the correction.

20 More particularly, any areas or portions of the image can be
21 optimized. First, the area needs to be identified. In a Graphics User Interface, this

1 is easily done using the mouse in a 'click and drag' operation. This can be done in
2 Object Oriented Programming by using the Operating System (Windows) to identify
3 when the mouse button has been clicked. In Visual Basic there are built in
4 subroutines (for every program) that are executed as soon as the mouse button is
5 depressed or released.

6 A user can select any rectangular area within the image. The
7 'coordinates' are stored in common memory as xdown, ydown, xup and yup. See the
8 photographic examples #1 and #2 for the superimposed rectangle on the image.

9 In both the Virtual Lens and the Virtual Detail Enhancement, I referred
10 to a 'modified histogram approach'. A histogram is simply the measurement of the
11 number of occurrences against the value of the occurrences.

12

1 For example, as shown in Table 4, in terms of a set of RGB triplets:

2 **Table 4 - Standard Histogram Approach**

3 "Red, Green, and Blue values taken as independent"

4	Dot #	Red	Green	Blue	Value	# Events
5	1	1	1	1		
6	2	0	0	1	0	2
7	3	2	2	1	1	11
8	4	4	3	1	2	3
9	5	4	4	4	3	7
10	6	3	2	1	4	5
11	7	5	1	1	5	2
12	8	3	3	1		
13	9	4	3	1	Total	30
14	10	3	3	5		

15 In this example, there are 10 dots each having 3 values (red, green
16 and blue) and each of these 30 values range in value from 0 to 5. The normal
17 histogram is calculated by adding up the number of times each value (0, 1, 2, 3, 4,
18 and 5) occurs in total.

19

The modified histogram approach, where strength = max(red, green, blue), described by Table 5 as follows:

Table 5 - Modified Histogram Approach

"Red, Green, and Blue values taken as a unit, Histogram on maximum"

Dot #	Red	Green	Blue	Strength	Value	# Events
1	1	1	1	1		
2	0	0	1	1	0	0
3	2	2	1	2	1	2
4	4	3	1	4	2	1
5	4	4	4	4	3	2
6	3	2	1	3	4	3
7	5	1	1	5	5	2
8	3	3	1	3		
9	4	3	1	4	Total	10
10	3	3	5	5		

Simply, it is the occurrence of numbers as found in the maximum strength that is used to build the histogram and not the values of red, green and blue separately.

This is in keeping with the nature of this patent application which is that red, green, and blue values are to be treated as a unit having a strength and ratios and not as three independent values.

The histogram is built by considering only those dots within the range of rows = xdwn to xup and columns = ydwn to yup.

Having reference to Fig. 7a, example code is provided by which to apply the modified histogram.

1 At this point, the histogram is formed and its running total is known
2 with respect to the strength of the RGB triplets of the marked area. The beginning
3 and the ending significant strengths are determined, as reflected by the histogram
4 data.

5 To avoid errors such as dead or saturated recording elements and
6 otherwise 'stray values' that are not representative of the area, one can limit the
7 relevant dots to the 2% and the 98% of the number of occurrences to represent the
8 smallest and largest relevant RGB strengths.

9 The number of strengths counted by the histogram, in total, is equal to
10 the last running total value, and the 2% and 98% values are, therefore, easily found.
11 Code is shown in Fig. 7b which determines the range of strength index (hmin and
12 hmax) corresponding to the range of strengths within the box selected by the user.

13 Having reference also to Fig. 4, the modified histogram approach
14 found 0.30 (of the dynamic range maximum) and 0.50 (of the dynamic range
15 maximum) to be the minimum and maximum strength values of the portion of the
16 image selected by the user. (See photographic examples #1, #2, for the boxes).

17 It was also assumed that the range calculated from the modified
18 histogram approach should be modified so that it varied over the majority of the
19 dynamic range.

20 So, what should this input range of hmin and hmax be turned into?
21 We want it to occupy most of the dynamic range. A good guess is 80% of the

1 dynamic range with a little left over for the darker and lighter areas so they can still
2 be used as a reference.

3 In application code, the output strength range of the selected area was
4 originally set to 0.1 to 0.9 of the dynamic range maximum. It was later reset to 0.2
5 to 0.9 as these numbers simply seemed better after observing many images.

6 The code used to calculate the look up table based on the modified
7 histogram approach for determining the input strength range and the (nearly)
8 arbitrary output range of 0.2 to 0.9 follows.

9 The graph of Fig. 4 can be thought of, in the general sense, as having
10 3 line segments each with two end points.

11 **Table 6: Line Segments:**

12	Line Segment	Start	Stop
13	#1	(0,0)	(xmin,0.20)
14	#2	(xmin,0.20)	(xmax,0.90)
15	#3	(xmax,0.90)	(1.0,1.0)

16 where xmin and xmax have been calculated by the modified histogram
17 approach. That is to say:

18
$$xmin = hmin / drmx$$

19
$$xmax = hmax / drmx$$

20 Both input axes are measured in terms of the dynamic range. The
21 input values are in terms of the strength (max of RGB) of the dot. The graph never

1 leaves the 0 to 1 'box'. These constraints must always be met by any scaling
2 function in any specific process.

3 All that remains, here, is that the output value be calculated by a
4 program equivalent to that described for Fig. 2 above and that the lookup table does
5 not hold the graph, exactly, but the ratio of the output to the input.

6 Each line segment can be expressed with algebra in the 'slope
7 intercept' form, of which the general form is: $y = m \cdot x + b$. For each of the three line
8 segments, linear equations and scaling factors are determined. An array of
9 corrections or scaling factors can be formed from the three equations. Dividing the
10 output values by the system dynamic range produces the ratio of output to input.

11 This virtual detail enhancement technique, or forensic flash due to its
12 ability to delve into the normally obscured areas, maximizes the dynamic range of
13 any target so that the details are enhanced. This is not restricted to the target area
14 but any part of the photograph that has similar strengths to the user's choice will
15 also be so enhanced. Any target area can be selected and so there can be many
16 valuable corrections performed on the same photograph. Those areas which were
17 stronger than the strength range picked by the user remain as useful references
18 due to the 'true color' nature of the correction.

19

20

1 Examples

2 Virtual Flash - Virtual Iris

3 The examples illustrated in Figs. 9 and 10 illustrate corrections to the
4 limitations that occur from the physical light gathering devices or image recorders.
5 The one aperture and shutter setting per frame means that a photograph is likely to
6 vary from one's memory of the experience of being there. The eye's iris adjusts
7 itself when experiencing contrasts. In a park on a sunny day, the iris opens up
8 when moving from sunlight to the shade so that you remember all the grass as
9 being green whereas photos often show shaded grass as black.

10

11 Photo #1 (Figs. 9a – 9f) Tourist photo of an Abbey

12 This example illustrates how various prior art processes and the
13 present invention enhance the image. The approach with the prior art processes is
14 to "play" with the image until the brightness looks about right for what you want. It is
15 a subjective thing and the expert user is someone who is good at making the
16 necessary compromises. In Fig. 9a, the original image, scanned from a
17 photograph, is very dark but still uses all/most of dynamic range (of the dot
18 maximums (hits) being outside the strengths of 5 and 254) of a system of 256.

19 Figs. 9b - 9d illustrate prior art image brightening techniques. Fig. 9b
20 does so by increasing the image brightness by 80%. While the image of Fig. 9b is
21 brighter, the colors are badly faded and the sky has also experienced change in

1 color. Fig. 9c illustrates the prior art brightened image of Fig. 9b with contrast set to
2 50%. Contrast is increased in an attempt to try to restore the colors lost in
3 brightening. Notice how much of the detail of the image is lost. The process has
4 pushed many of the dots past the edge - outside of the dynamic range. Fig. 9d
5 illustrates the brightened image of Fig. 9b with the saturation set to 50%. Increase
6 in saturation is another technique for restoring the colors. As a result, the sky is
7 almost returned to what it was but the rest of the image has significant and unsightly
8 color distortions.

9 Applying the techniques of the present invention, the photo fairs much
10 better particularly in Fig. 9f. In Fig. 9e, the image range of 5 to 254 is linearly
11 mapped to 0 to 255. The effect is small because the original image was nearly full
12 range already. It does, however, ensure that we have the full dynamic range in the
13 output image. In Fig. 9f, the scaling function of Fig. 8 was applied for obtaining a
14 superior image. All the colors are true to the image, as it was scanned, and are
15 vibrant, just as they would have been to the eye with no loss of detail.

16
17 Photo #2 (Figs. 10a – 10f) Tourist photo of Stone Henge

18 In the original frame of Fig. 10a, the stones are in the shadows due to
19 the extreme lighting conditions. In Fig. 10f, the virtual iris process of the present
20 invention compensates in a similar way that the iris does automatically, turning the
21 poor photo into a good one.

1 More particularly, in Fig. 10a, the subject is very dark and again uses
2 all/most of dynamic range (only 1% of the hits being outside of a strength of 6 and
3 253). This image had been "pre-processed" by others to bring out detail - notice
4 how the sky is nearly white but clouds are still available (reproduction of the Figures
5 in this application does not necessarily preserve the actual presence of the clouds).
6 The prior art had taken it "as far" as its could but the subject was still too dark. Fig.
7 10b illustrates prior art brightening of the image by 60%. While image is brighter,
8 the colors are badly faded and the stones have lost all their color. Some of the
9 detail is also lost by this process alone. Note, even in the gray-scale rendering, the
10 whitening of the "red" rock left of the stones and at the left extreme of Fig. 10b
11 image. Fig. 10c is the brightened image of Fig. 10b with contrast set to 40%. Notice
12 that the stones have, in areas, regained some color but not in other areas. Also
13 notice how much more of the detail of the image is lost. Fig. 10d is the brightened
14 image of Fig. 10b with saturation set to 15%. There is improved color that is "sort of
15 right in a way" but it also adds artificial colors, such as some reds and yellows.
16 Even in photos where not much correction is needed, manipulation of saturation for
17 each dot ends up with different RGB ratios than were recorded. At best, one ends
18 up with a compromise solution.

19 Applying the techniques of the present invention, in Fig. 10e the image
20 range of 6 to 253 is linearly mapped to 0 to 255 to ensure the full dynamic range in
21 the output image. In Fig. 10f, the scaling function of Fig. 8 was again applied for
22 obtaining the superior, true color image with no loss of detail.

1

2 Forensic Flash - Virtual Detail Enhancement

3 Photo #3 (Figs. 11a,11b) Satellite

4 In Fig. 11a, the satellite is in the shadows and the surface is very dark.
5 This often happens in space because of the extreme contrast in lighting. Important
6 'docking' holes cannot be seen. Using the forensic flash correction technique of the
7 third embodiment, a window or box was selected within the dark area and the
8 histogram approach used to build a correction graph suited for that area.

9 In Fig. 11b, the processed image now shows the detail in the dark
10 area. The docking holes, marked with white circles, are now revealed.

11

12 Photo #4 (Fig. 12a,12b) Blimp

13 In the original image of Fig. 12a, the underside of the blimp is in the
14 shadows. This often happens in photography when the lens is directed into the sky.
15 Specifically, the identification markings cannot be seen as the tail is too dark.

16 Under the principles of the third embodiment, the tail area is selected
17 and the histogram approach used to build a correction graph suited for that area.
18 As a result, as shown in Fig. 12b, the processed image shows the lettering in the
19 previously obscured, dark area. The blimp is now identified as COLUMBIA N3A.

20

1 Photo #5 (Fig. 13a,13b) Car Plate

2 In the original frame of Fig. 13a, the car's license plate is mostly
3 shrouded in shadows. The car cannot be identified because the plate cannot be
4 read. Using the third embodiment, the plate is selected and the histogram approach
5 used to build a correction graph suited for that area.

6 As a result, and referring to Fig. 13b, the processed image shows that
7 the car does not have a normal plate at all but, instead, the words: Classic Mustang.

8

9 Photo #6 (Fig.14a, 14b, 14c) Tracks in the Snow

10 In Fig. 14a, there are two people skiing. Their tracks are identifiable,
11 but subtle. Using the forensic flash correction technique of the third embodiment, a
12 window or box was selected within the overexposed area of the tracks in the snow
13 and the histogram approach used to build a correction graph suited for that area.

14 In Fig. 14b, the processed image now shows the detail in the
15 overexposed area. The tracks in the snow are distinctly visible.

16 Similarly, a window or box was selected in the dark area of the face of
17 the skier in the photograph. Figure 14c is the result of the histogram approach used
18 to build a correction graph uniquely suited to this area of the photo. The features of
19 the skier are more clearly visible than in the original photo shown in Fig. 14a.

20

21

1 Summary

2 The key concepts are here expressed as the combination of the
3 following six factors: correcting in RGB color space, the correction graph; the
4 definition of the correction axes; constraint of domain and range to the system's
5 dynamic range; properties of the graph; and application of the same correction
6 factor to each of R,G and B in the triplet.

7 The correction must be applied to the RGB color space to maintain
8 true color. Any correction graph can be used that embodies the above
9 characteristics. Both the input and the output axes represent the maximum of the
10 RGB triplet. The input is the maximum of the RGB triplet under consideration and
11 the output corresponds to the maximum of the RGB triplet that is calculated as a
12 result of virtual true color light amplification. The correction is constrained to the
13 dynamic range. This means that the strength of the calculated dot is constrained to
14 the dynamic range. Any graph that can be plotted within the constraints can be
15 used for the process. The properties of a particular graph will affect the emphasis
16 of the correction. Again, all three of the RGB values must be multiplied by the
17 scaling factor derived from the graph. A given point on the graph has an input and
18 output value. The correction equals the ratio (division) of these two and all three of
19 the RGB triplet values are multiplied by this ratio of output to input.

20 The result of these considerations is a suite of processes all of which
21 preserve the essential color of each and every dot in the input digital image while
22 varying the effective light gathering power which can easily be on a dot to dot basis.

1 All that differs between the above embodiments is to vary the graph
2 within the imposed constraints. With virtual true color light amplification, a new and
3 useful result is dependent only upon identifying an image enhancing need and
4 identifying a reasonable graph to fit that need.

5

6 CORRECTION OF FADED IMAGES

7 In a preferred aspect of the invention there is an additional automatic
8 correction which can be applied to supplied images which are degraded, those that
9 look faded but lack the natural chaos in the degradation. Through investigation, it
10 appears to applicant that this is a common problem of images. The problem is that
11 there appears to be a constant triplet of gray added to these classes of photograph.
12 Grays are represented by a triplet where R, G, and B at any strength have the same
13 value. Examples of grays are:

14	Bright White	(255, 255, 255)
15	White	(200, 200, 200)
16	Light Gray	(150, 150, 150)
17	Gray	(100, 100, 100)
18	Dark Gray	(50, 50, 50)
19	Black	(0, 0, 0)

20 Images, such as a red beach ball, might be represented by a triplet
21 (150, 50, 50) and thus look pink instead of being truly red at (100, 0, 0). The Virtual
22 True Color Light Amplification process described above and in co-pending
23 application 09/548,755 cannot correct these photos as it assumes that the input

1 (150, 50, 50) is the right color to begin with. A non-faded photograph is likely to
2 contain a representation of vibrant color, being that one or more of R, G, or B is
3 zero. Some examples are:

4	Bright Red	(255, 0, 0)
5	Bright Yellow	(255, 255, 0)
6	Bright Blue	(0, 0, 255)
7	Dark Red	(63, 0, 0)
8	Dark Yellow	(63, 63, 0)
9	Dark Blue	(0, 0, 63)

10 Mathematically, the existence of vibrant color means that the smallest
11 strength values for R, G or B encountered in the image should be zero, or near
12 zero. In faded images, the smallest values are non-zero which applicant suggests
13 are artificial and represent the addition of gray throughput.

14 In order to remove this artificial addition of gray from the image the
15 assumption is made that the smallest numbers encountered in the image would
16 actually have been zeros if there had been no degradation or distortion. An offset
17 value, x , is determined so as to reduce the gray to zero. This offset (x, x, x) is
18 subtracted from each of R, G and B.

19 With reference to Figs. 18a and 18b, to automatically determine the
20 value of the offset x , a first histogram of all the independent values of R, G and B is
21 made of the image. To reject outliers, a majority of the population of color dots is
22 retained by setting the offset x at a clipping threshold, rejecting 0.1% - 0.5% of the
23 population of strength values which is equivalent to retaining 99.9 to 99.5 % of the

1 values. The difference between the strength value at the clipping threshold and the
2 minimum of the dynamic range (typically zero) is selected as the offset value x . As
3 shown in Fig. 19b, the removal of (x, x, x) from each R, G and B ($R-x, G-x, B-x$) shifts
4 the histogram to the left which is also the minimum strength of the dynamic range.
5 Essentially offset x is shifted to zero which has the result of making the supplied
6 image appear somewhat darker. Basically for faded images, there is an advantage
7 in first darkening an image before seeking to brighten or adjust the supplied image.

9 AUTOMATIC STRENGTH SELECTION

10 If the supplied image is not faded or otherwise contain an
11 inappropriate amount of gray, then the supplied image becomes an original image
12 for brightening. If there is gray in the supplied image, it is preferable to
13 automatically offset the strength values of the supplied image to arrive at a new
14 image, an original image, for brightening. Note that when the offset approach is
15 applied, it purposefully results in color distortion as it manipulates the strength of
16 each of R, G and B in different proportions.

17 The true color brightening or light amplification techniques,
18 implemented herein, as set forth in the co-pending application and reproduced
19 substantially above, brighten images based on a function selected by the user or
20 pre-selected for correction at some pre-determined amount, all without exceeding
21 the dynamic range and also without color distortion. However, aesthetics are rarely
22 that simplistic or universally applicable. Herein, applicant has also sought means to

1 automate the brightening process and thereby relieve the user, typically a novice, of
2 the need to assess an ideal brightening function.

3 An automatic strength selection process of the present invention can
4 be applied to almost all photographs with little harm. The process is based on the
5 assumption that there is an average strength value applicable to most photographs
6 which is pleasing to the eye. Empirical study for this applicant has determined that
7 there can be a target average strength which is suitable to most photographs.
8 While this is based substantially on aesthetics, a range of target average strength
9 can be usefully between 50 and 65 % of the dynamic range. A different target may
10 be chosen by others, but nevertheless, an infinite number of different images can be
11 corrected to a target average strength once selected.

12 In correcting an image to a target average strength, applicant has
13 avoided complex polynomial analysis where one might specify a different
14 polynomial function for every image of an infinite possible number of images.
15 Instead, while acknowledging that a preferred function for correcting a range of
16 strengths present in an image can be a non-linear function, images are corrected to
17 a more true-to-life color through simple interpolation of the results between a given
18 function and a linear identity function (both of which are shown in Fig. 8) to
19 determine what scaling factors will produce an image at the target strength value.
20 Herein for simplicity of language, interpolation is intended to include extrapolation,
21 both of which are merely estimates of a value from a function where other values of
22 that function are known.

1 In an illustrative embodiment, an improved image enhancement
2 process adapts the non-linear and continuous virtual iris curve to automatically
3 obtain scaling factors for correcting the color of a digital image. Such a curve is
4 shown in Fig. 8 as introduced in co-pending application 09/548,755. Other
5 specialized curves illustrated in Figs. 4 and 6. The form and selection of the
6 constants for the function are pre-determined, which does not adapt to the infinite
7 variety of images. Applicant has determined a method for automatically adapting
8 the function on an image by image basis.

9 With reference to Fig. 19, herein, a 100% correction refers to direct
10 application of a form of the virtual true color light amplification function to correct an
11 image as shown as function C in Fig. 19 (also as Fig. 8). As stated, while the image
12 is brightened and the color may remain true, this 100% correction may not provide
13 an optimal aesthetic effect. Instead, an optimal or target correction has been found
14 empirically to lie between the 100% correction and no correction at all, represented
15 by function T. An identity function is a 0% correction, where no brightening is
16 performed at all, illustrated as the diagonal linear line in Fig. 8.

17 With reference also to Fig. 20, simply, for establishing the form of
18 function T, a second original histogram H_o of the strengths of the dot maximum for
19 each color dot in the original given image is obtained and an original average
20 strength STR_{ORIG} is established. A third correction histogram H_c is obtained after a
21 100% color amplification (function C) is applied to the original histogram and to
22 establish a corrected average strength STR_{CORR} ; this correction being made

1 according to the invention so as ensure maintenance of the colors of the original
2 given image and within the dynamic range. The corrected average strength
3 STR_{CORR} is compared to a target average strength STR_{TAR} and scaling factors of
4 the color correction are adjusted accordingly and while not a required step, a fourth
5 histogram H_T can be established.

6 Mathematical operations are preferably performed at the histogram
7 level representing a set of values of individual primary colors R,G and B. Using a
8 histogram, one scaling factor can determined which corresponds to one dot
9 maximum which potentially represents a very large number of like color dots, all of
10 which have the same dot maximum. This enables an image having millions of color
11 dots to have a corresponding, manageable and computationally efficient 256 scaling
12 factors representing the whole image.

13 The original image may be as received or as previously adjusted using
14 the faded image correction having been shifted by the offset x.

15 In this embodiment, the first histogram H_s of a supplied image (Fig.
16 18a) is shifted by offset x. A second and original histogram H_o (of dot maximums
17 Fig. 18b) of this new original image can be determined as the beginning point for
18 brightening the image. This new offset image forms the original image used for
19 automatic strength selection as follows.

20 With reference to Figs. 19 and 20, an average strength of the offset
21 original image, STR_{ORIG} , can be calculated from the histogram H_o (Fig. 18b and Fig.

1 20). An identity function applied to this histogram H_0 would result in 0% correction
2 and all the same strength values as in this original image.

3 The virtual iris enhancement function C is then applied at the 100%
4 correction for applying corresponding scaling factors selected from function C for
5 each dot maximum of the histogram H_0 , the scaling factor being applied to each of
6 the R,G and B of each color dot so as to maintain the true color of the color dot from
7 the original image.

8 The third corrected histogram H_c can be created of the corrected
9 image. Clearly, the formation of this and other histograms is purely a mathematical
10 concept and no representation like Figs. 18a,18b and 20 need be produced. A
11 corrected average-strength, STR_{CORR} , is determined from the values representing
12 the corrected histogram H_c .

13 Where the target average strength, STR_{TAR} , has been determined
14 empirically, for example such as at 158 of a dynamic range of 255 (58%) we can
15 determine whether the 100% correction was too aggressive and if a fractional
16 correction should be applied. A fractional correction %CORR or interpolation
17 constant can be determined through linear interpolation where,

$$\begin{aligned} 18 \quad \%CORR &= \frac{(STR_{TAR} - STR_{ORIG})}{(STR_{CORR} - STR_{ORIG})} * 100\%. \\ 19 \end{aligned}$$

20 While the interpolation constant can be applied as directly calculated
21 from the interpolation, the variability of images can result in unpredictable results.
22 Accordingly, correction to the image can be constrained so that images are not

1 corrected more than 80% as a safeguard to the automatic process. Accordingly, for
2 this embodiment and the function C set forth in Figs. 8 and 19, it is assumed that
3 correction about 100% is too aggressive and should be bounded by about an 80%
4 interpolation tempered with a lesser and fractional correction. In mathematical
5 terms, the constraints are:

6 %CORR = 100% correction – too aggressive
7 thus 100% %CORR > 80% = 80%
8 0% < %CORR 80% = %CORR
9 %CORR 0% = 0%

10 The virtual iris curve or function C is non-linear but the interpolated
11 displacement from 100% of the virtual iris curve to the interpolated or target function
12 T is a linear interpolation. It is in this sense that the linear interpolation is performed
13 on a non-linear functions.

14

15 Example

16 A brightly distorted and supplied image can be represented in a
17 histogram Hs as in Fig. 18a. To determine the offset x, we take the value at 0.1%
18 on the histogram, here x= 104 for a dynamic range of 0-255. The triplet (104, 104,
19 104) is subtracted from each R, G, and B dot in the image and the second
20 histogram Ho is created representing an original image, as in Fig. 18b and
21 reproduced on Fig. 20.

1 Now the original image is brightened without distortion of the colors.
2 The mean, or average strength, of the original image, STR_{ORIG} , is found to be 95,
3 being a fractional 0.37 or 37% of the dynamic range

4 With reference to Fig. 19, the virtual iris curve is applied to the original
5 image. Assume there were 6400 color dots in the image having dot maximum
6 strength values of strength 61. Application of the identity function (0% correction)
7 would maintain all 6400 values as a strength value of 61, that is the image would be
8 unchanged. When the virtual iris non-linear curve is applied to the image and a
9 third correction histogram H_c is created, the 6400 values at an original strength 61
10 are scaled to the value corresponding on the full or 100% virtual iris curve, say a n
11 amplified or brightened strength value of 79. Only one scaling factor $0.79 / 0.61 =$
12 1.295 need be calculated for each dot maximum which is applicable equally to each
13 of R,G, and B in each of the 6400 dots in the image which all have the same
14 strength. Similar adjustments are made to all strength levels within the dynamic
15 range, scaling factors from the function C being applied to each dot maximum
16 represented in the histogram H_o .

17 From the correction histogram H_c of corrected strength values, a new
18 mean, or corrected average-strength, STR_{CORR} , is determined to be 170, being a
19 fractional 0.67, or 67% of the dynamic range. We now know:

20 $STR_{ORIG} = 95$ (37%), $STR_{CORR} = 170$ (67%) and $STR_{TAR} = 158$ (58%)
21 To determine the automatic correction factor, %CORR, for the image
22 we can apply the %CORR formula as follows:

$$\begin{aligned} 1 \quad & \% \text{ CORR} = ((\text{STR}_{\text{TAR}} - \text{STR}_{\text{ORIG}}) / (\text{STR}_{\text{CORR}} - \text{STR}_{\text{ORIG}})) * 100\% \\ 2 \quad & \% \text{ CORR} = ((158 - 95) / (170 - 95)) * 100\% \\ 3 \quad & \% \text{ CORR} = (63 / 75) * 100 = 84\% \end{aligned}$$

4 The interpolated constant %CORR represents the shift in the scaling
5 factor between the identify function Z and function C. Accordingly, for the target
6 correction, for all 6400 dots at strength 0.61 the appropriate scaling factor is no
7 longer 1.295 as determined at the 100% correction but is now an interpolated target
8 scaling factor TSF which is established for each original dot maximum and is
9 determined as follows:

$$\begin{aligned} 10 \quad & \text{TSF} = \frac{(\% \text{ CORR} * (\text{DotMax}_{\text{CORRECTED}} - \text{DotMax}_{\text{ORIGINAL}}) + \text{DotMax}_{\text{ORIGINAL}})}{100 * \text{DotMax}_{\text{ORIGINAL}}} \\ 11 \quad & \end{aligned}$$

12 where: DotMaxCORRECTED represents the corrected dot maximum, and
13 DotMaxORIGINAL represents the original dot maximum.

14 Accordingly the target scaling factor TSF for dot maximums at 0.61 of
15 the dynamic range is now (0.84 * (0.79-0.61) + 0.61) / 0.61 = 1.248. Similar target
16 scaling factors are determined for each dot maximum strength in the original image,
17 adjusted to 84% of the 100% correction curve scaling factors. Accordingly, scaling
18 factors at 84% of the Virtual Iris curve are applied to the original image, represented
19 by function T, automatically creating an adjusted image having eye-pleasing color
20 that is not distorted.

21 This example image turns out be to already be a fairly bright image
22 and one can further apply an arbitrary constraint to avoid overbrightening – judged
23 solely on an esthetics basis, and thus where %CORR > 80%, then %CORR = 80%

1 This image corrected at 80% will result in an average strength in this
2 case of 155. The scaling factors is therefore further suppressed slightly, the
3 resulting scaling factor for a dot maximum at 61 being (0.80 * (0.79-0.61) + 0.61) /
4 0.61 = 1.236.

5

6 Virtual Iris Functions Figs. 8 , 19

7 The form of the function is specified empirically. The preferred virtual
8 iris curve or function C of Fig. 8 and 19 is created by applying two separate non-
9 linear functions to the no-correction line, shown here as an exponential and a
10 logarithmic curve. Similarly, other functions include squared and square root
11 functions. Other functions include suitably bounded polynomials and stepwise
12 linear functions..

13 A pleasing correction is possible using the function or functions as set
14 forth in Fig. 19 wherein a first exponential function C_i ends where the second
15 logarithmic function C_{ii} begins. This is a predetermined anchor strength value x_0
16 intersecting the identify function or no-correction line Z and which is intermediate
17 the minimum and the maximum of the dynamic range. The intersection x_0 has been
18 determined empirically and for a dynamic range of 256 with the minimum at 0, X_0 is
19 set approximately as follows:

20 $x_0 = 0$ for a high quality image
21 $x_0 = 2$ for a clean image
22 $x_0 = 25$ for a noisy image

1 The first function C_i is applied to the darkest area of the image
2 between DR_{min} as the minimum of the dynamic range and the anchor strength value
3 X_0 , and which minimized an effect on the darkest area. The curve is exponential
4 and has the form of $f(x) = a + 10^{bx}$ where, $DR_{min} \leq x < x_0$, and $f(DR_{min}) = DR_{min}$;
5 $f(x_0)=x_0$. Typically DR_{min} is zero and the limits are $0 \leq x < x_0$ and accordingly $f(0)=0$.

6 The second function C_{ii} is applied to the brighter areas of the image
7 between the anchor strength value X_0 and DR_{max} as the maximum of the dynamic
8 range and has the effect of imitating the iris so that the output image happens to
9 more closely resemble one's visual memory of the experience. This curve is
10 logarithmic and has the form of $f(x) = a + \log_{10}(bx)$ where $x_0 \leq x < DR_{max}$ so that
11 $f(x_0)=x_0$ and $f(DR_{max}) = DR_{max}$. Typically a normalized DR_{max} is unity and the limits
12 become $x_0 \leq x < 1$ and accordingly $f(1)=1$.

13 This invention has been described in detail with reference to particular
14 embodiments thereof, but it will be understood that various other modifications can
15 be applied within the spirit and scope of the invention. For example, different target
16 average strengths may be preferred by others, different true color correction
17 functions C can be applied as described herein, being linear, non-linear or
18 combinations thereof. Further, many methodologies for computation analysis can
19 be implemented to maximize efficiencies. Herein, histograms are applied to
20 minimize the number of intensive calculations which is particularly important as
21 dynamic range increases from 256, to 1024 and upwards, however, other less

- 1 efficient (color dot-by-dot) or other more efficient techniques can be applied and still
- 2 achieve adjustment of an image without departing from the scope of the invention.
- 3